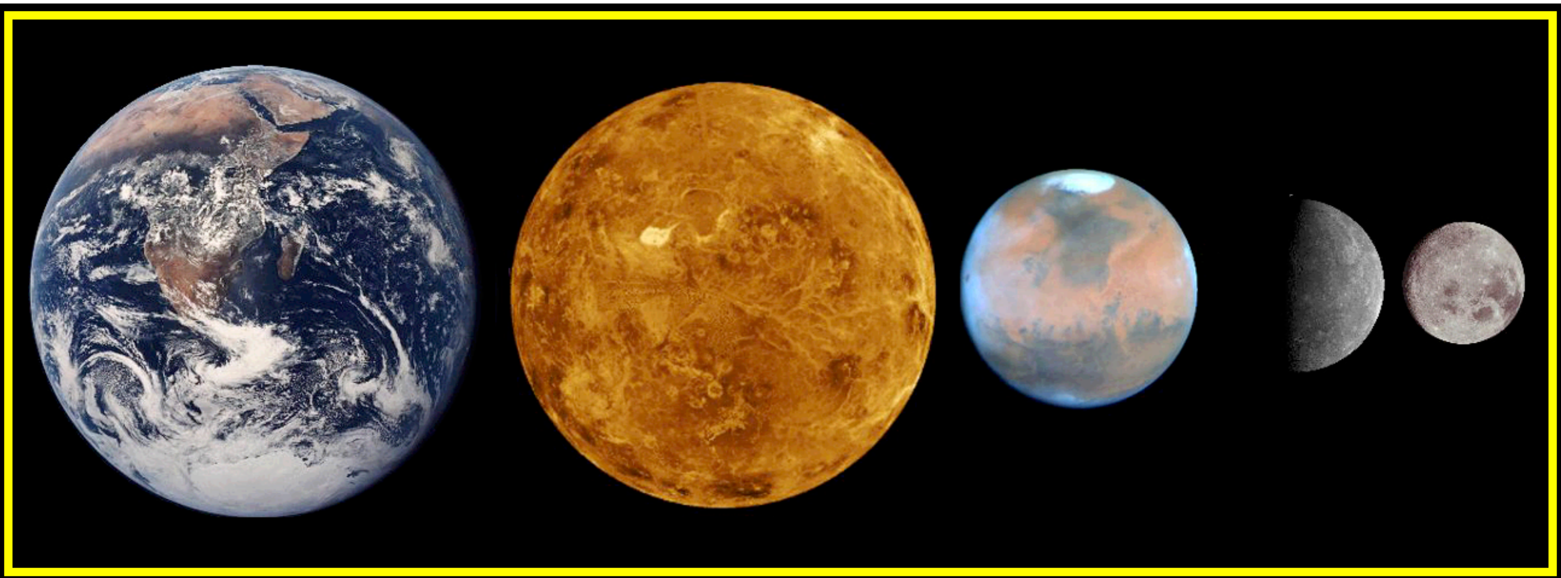
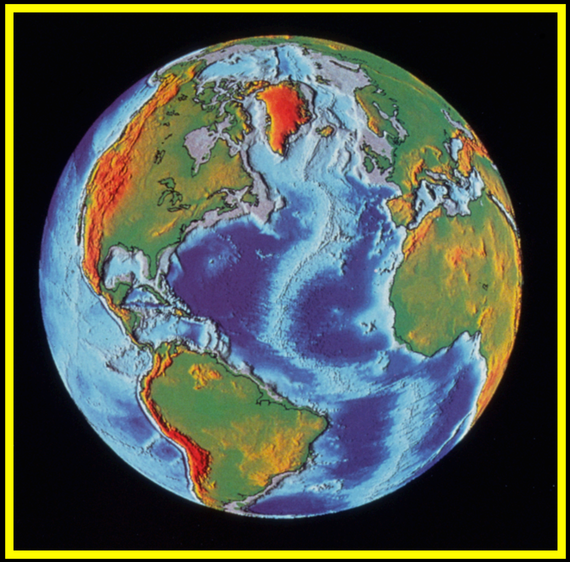


The Role of Basaltic Volcanism in Lunar Evolution: Testing Models of Petrogenesis



James W. Head
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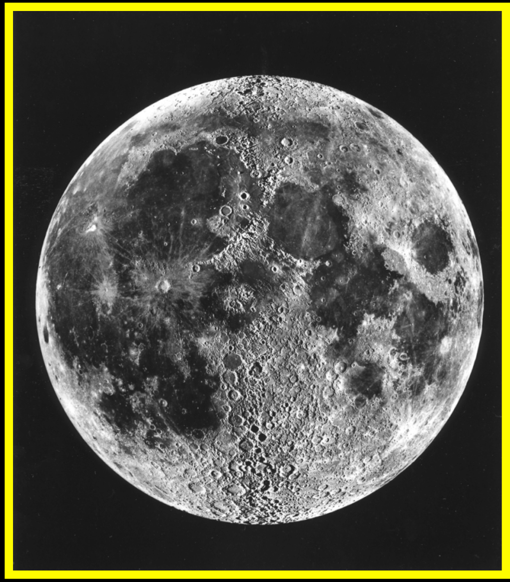
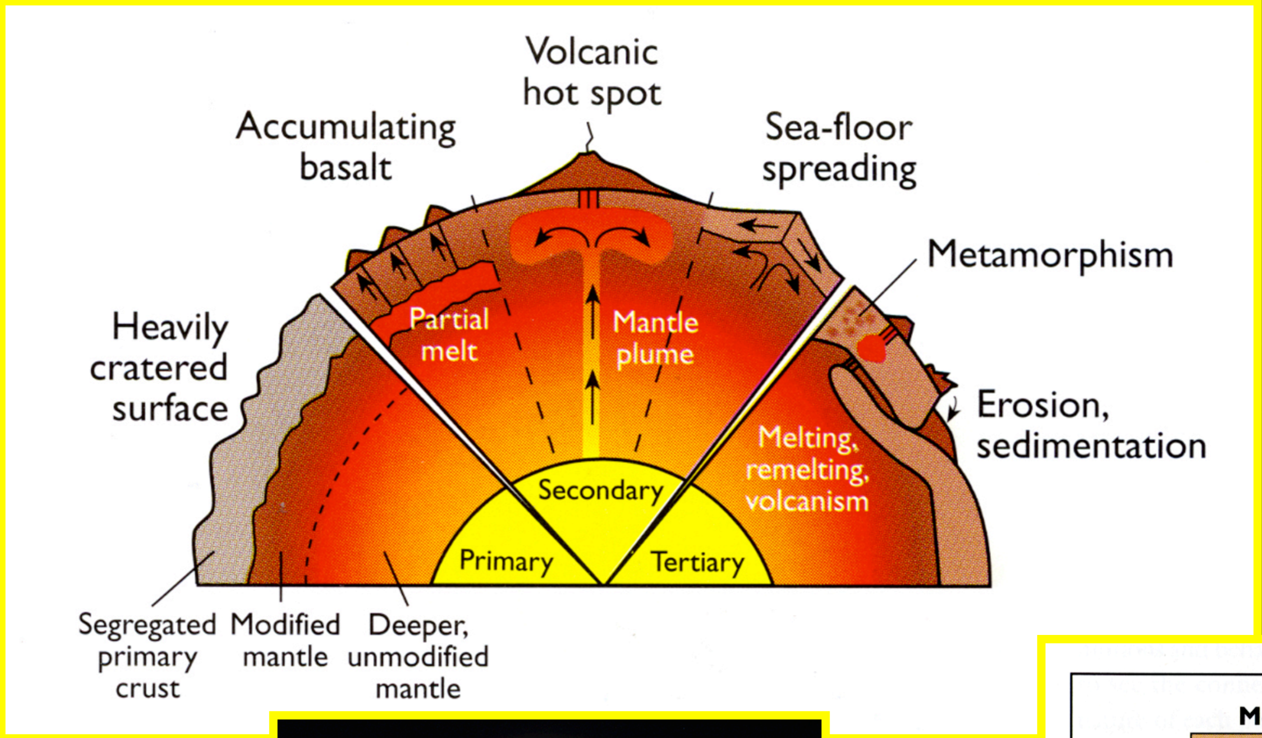
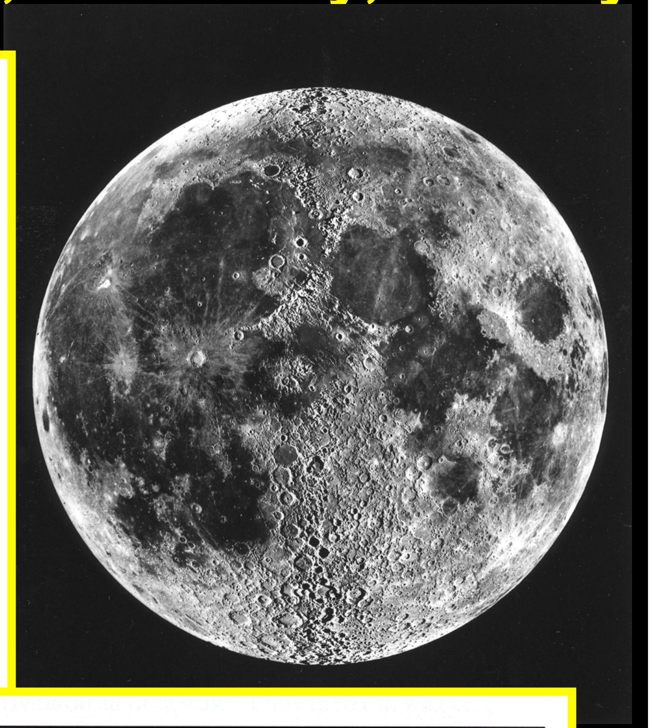
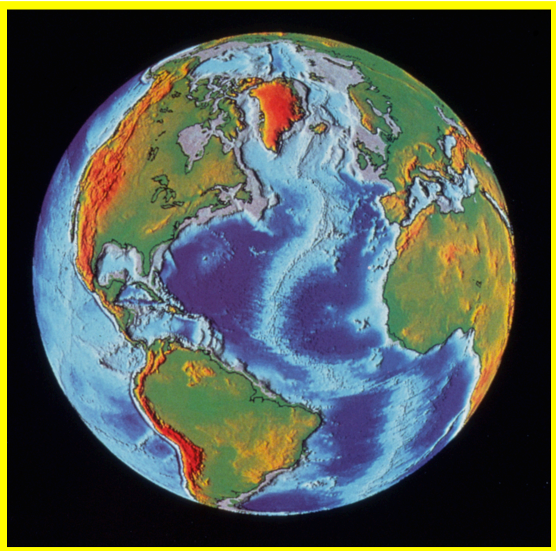


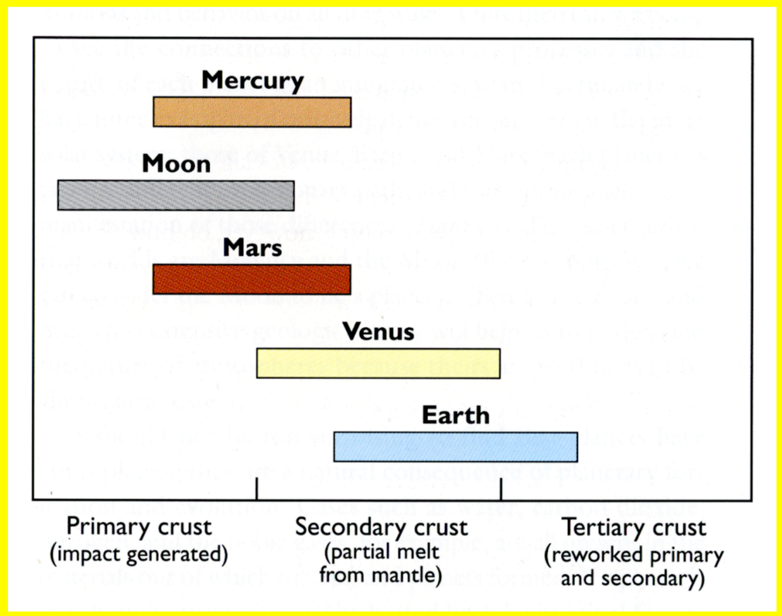
Crustal Formation and Evolution: Primary, Secondary, Tertiary



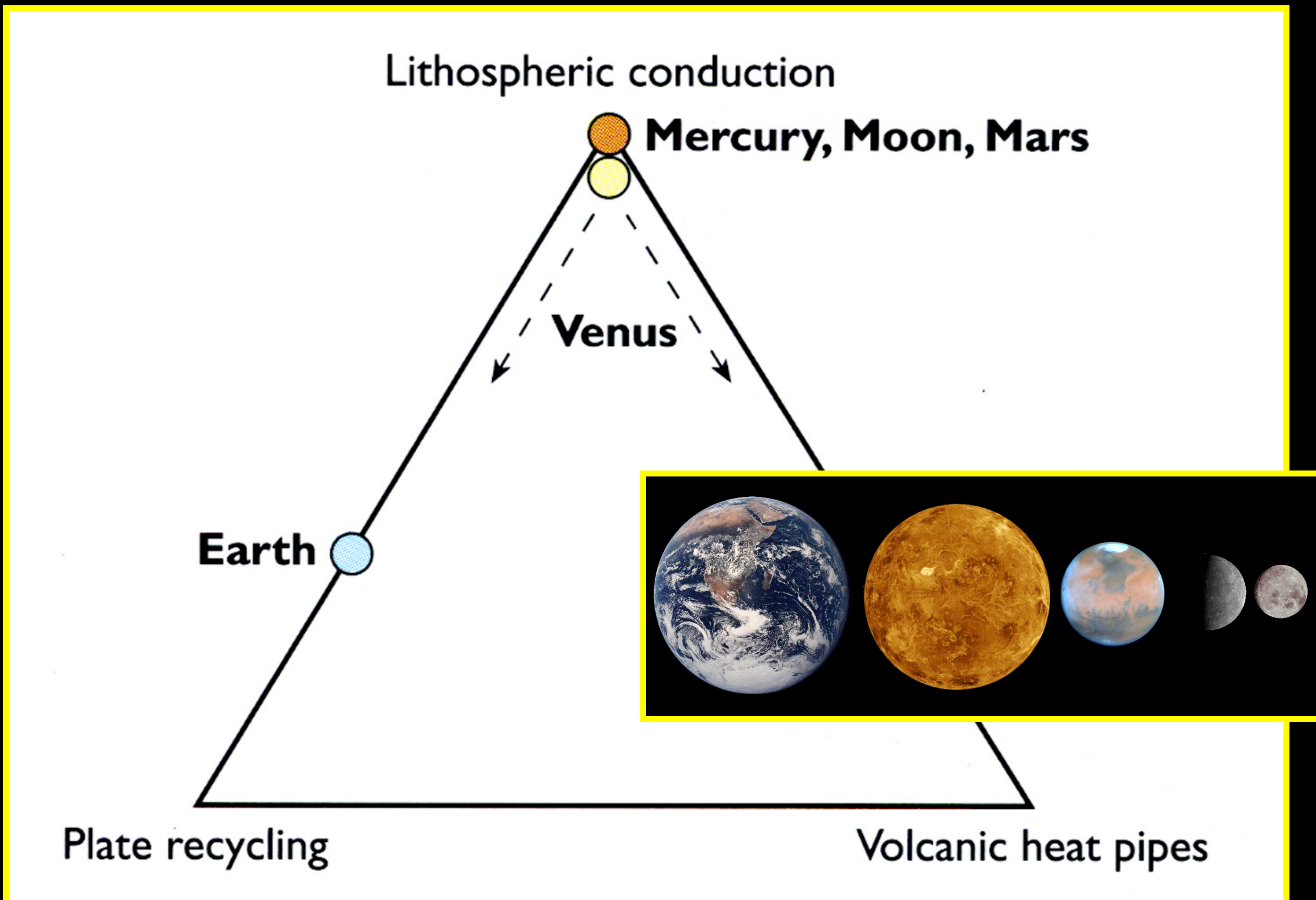


S. R. Taylor

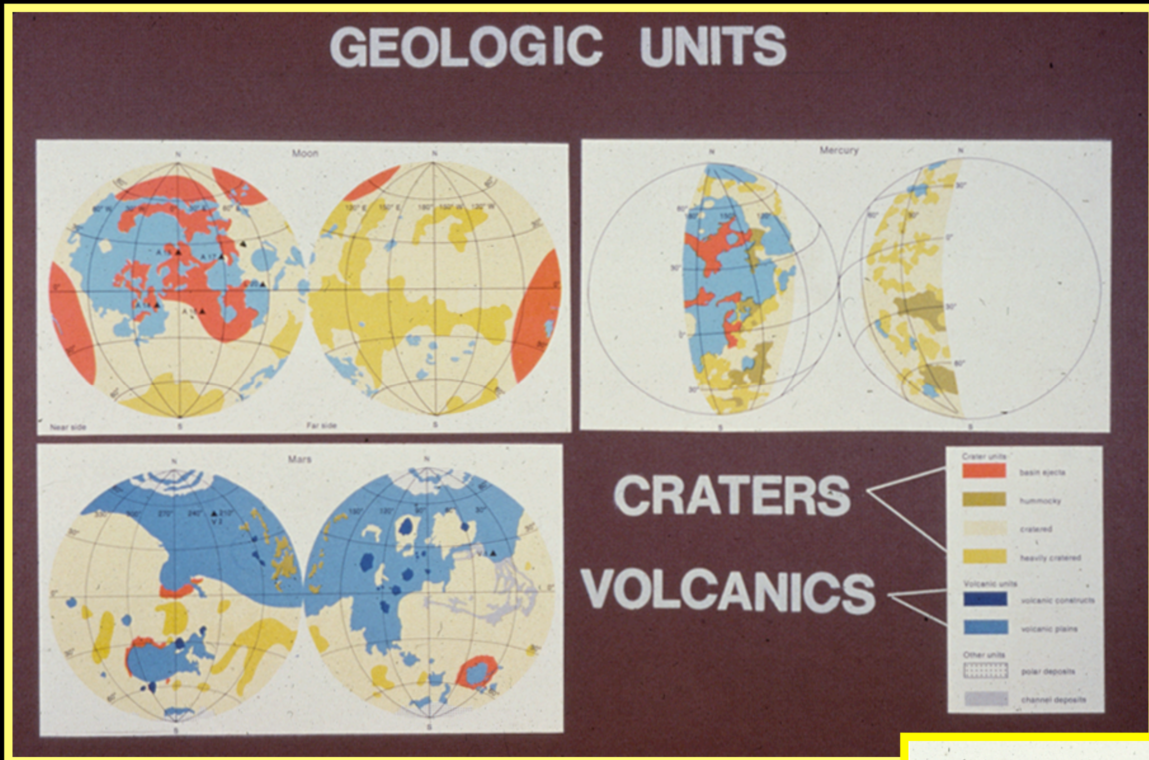




Mechanisms of Lithospheric Heat Transfer



S. C. Solomon

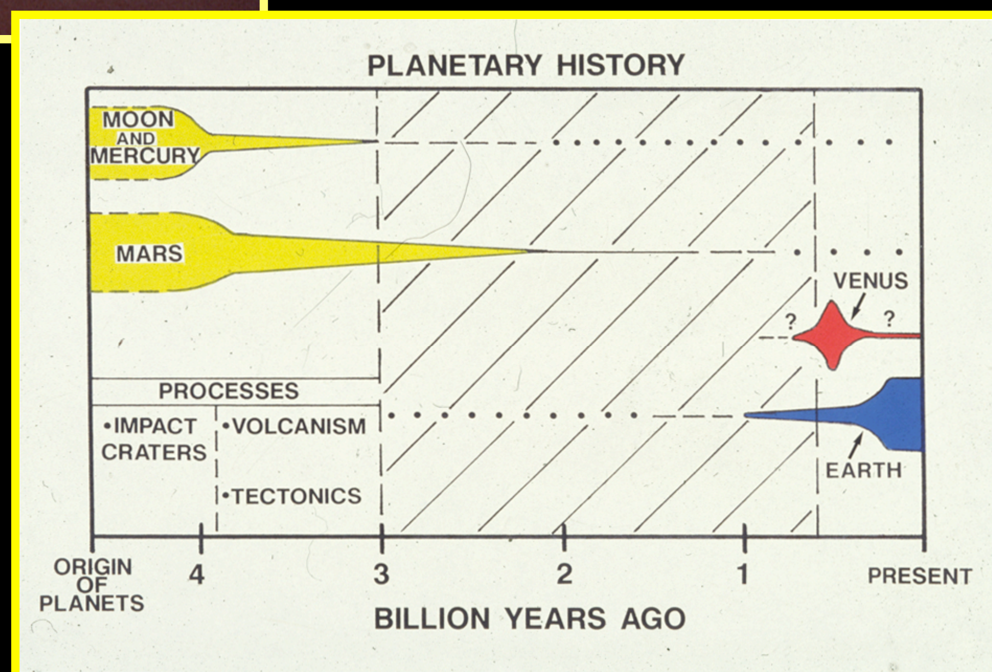


Geology of the Moon, Mercury and Mars: "One-Plate Planets" in contrast to Earth.

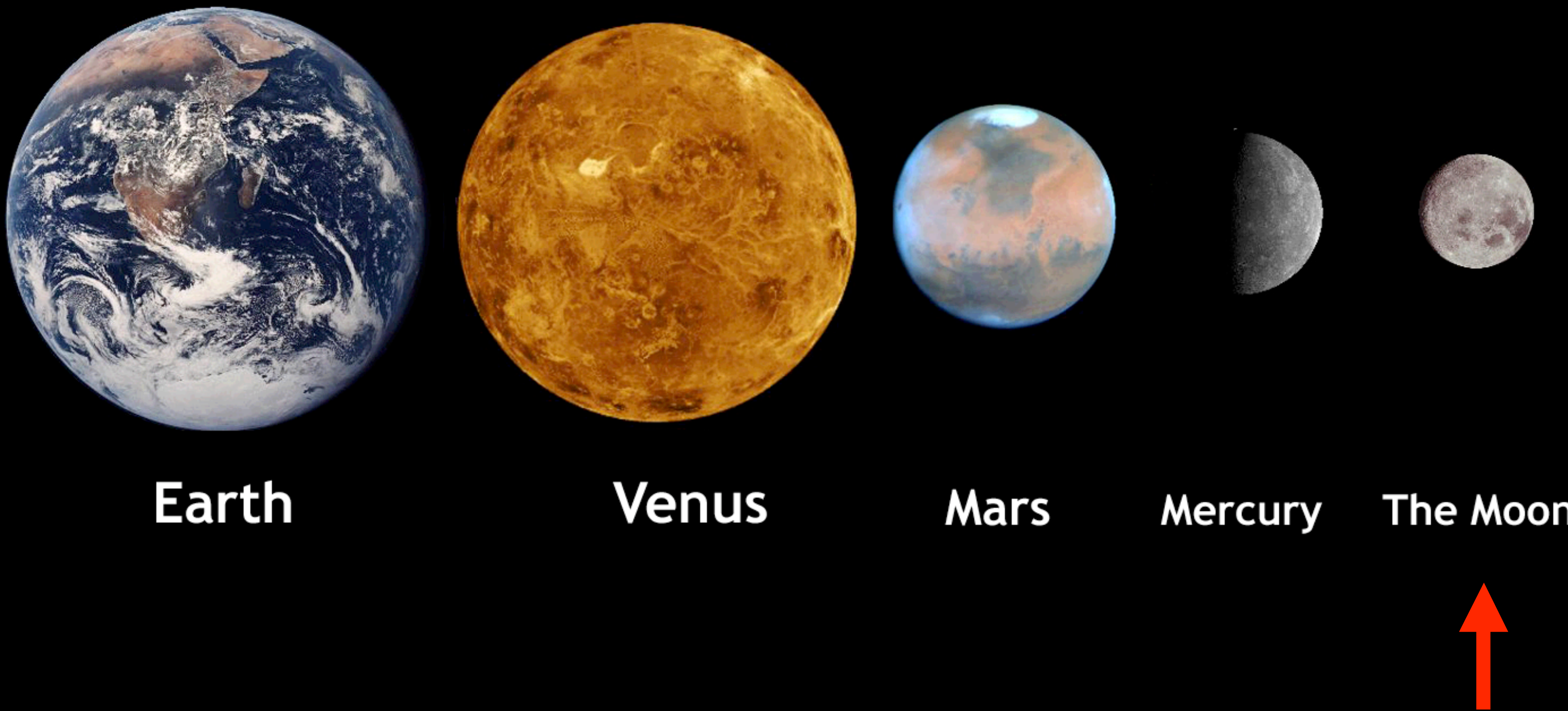
S. C. Solomon

The Moon is the place to study secondary crustal formation processes in early Solar System history.

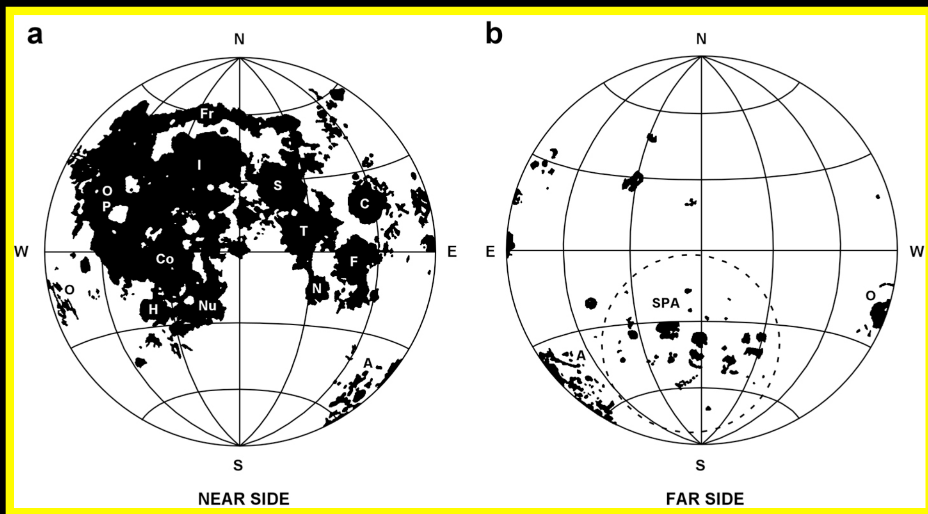
-How do mare basalts form?
-What does this tell us about the nature and evolution of the mantle?

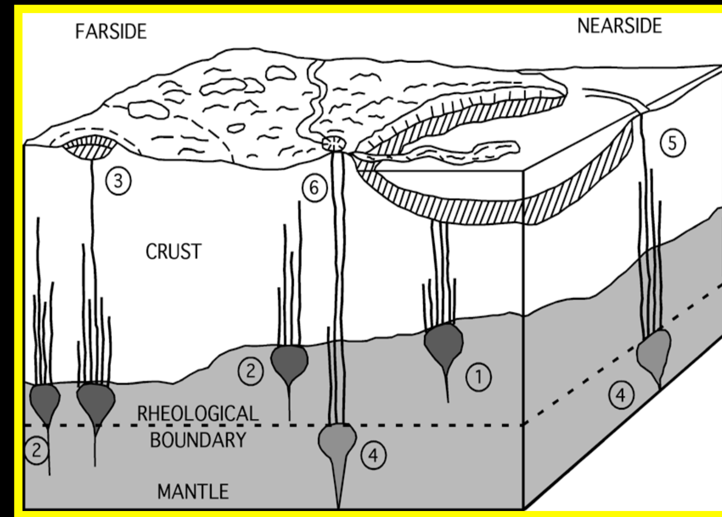


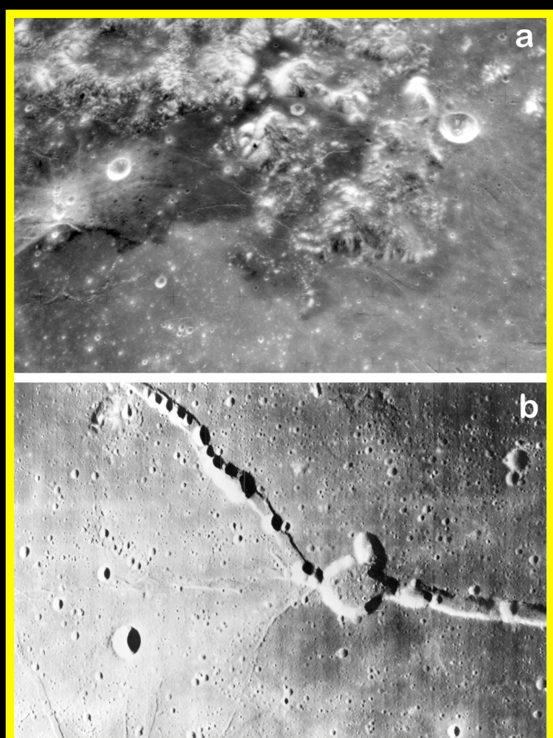
Terrestrial Planet Comparative Planetology

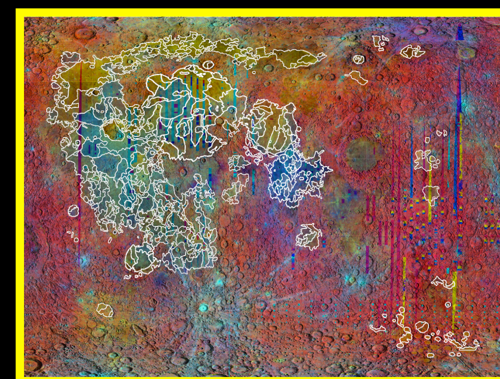


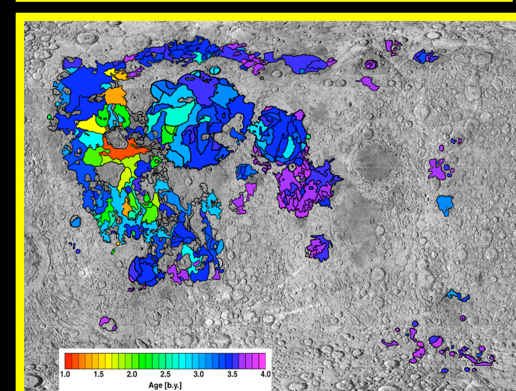
Lunar Mare Volcanism





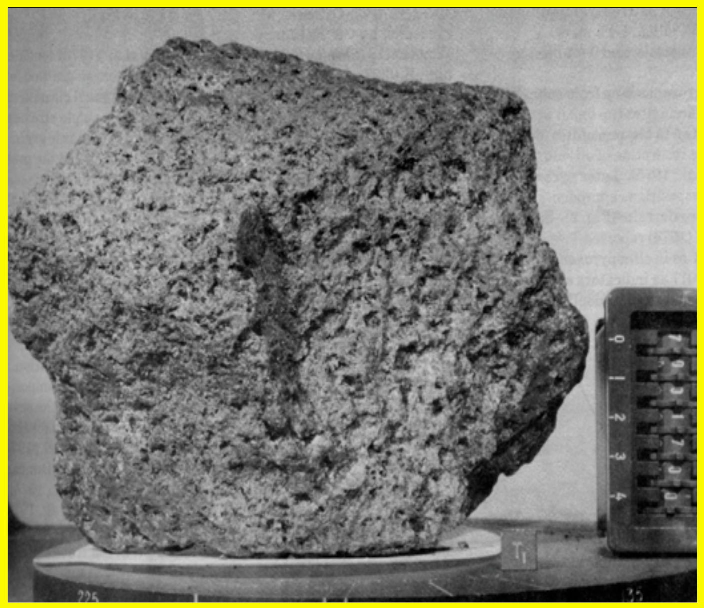






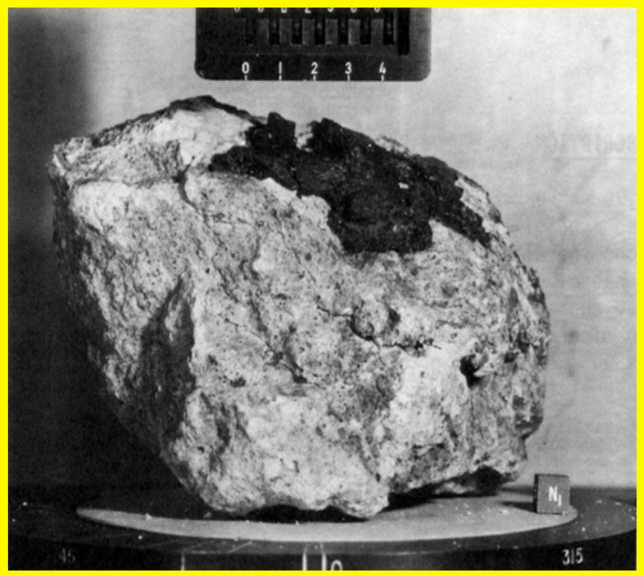
The Lunar Samples

Low TiO_2 Basalt 12002



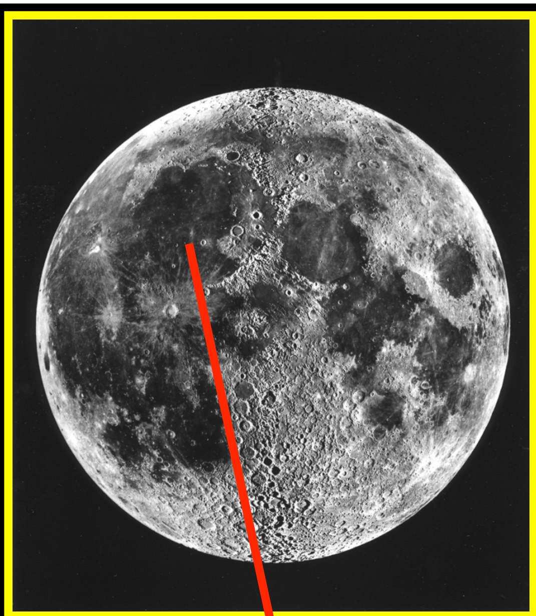
High TiO_2 Basalt 70017

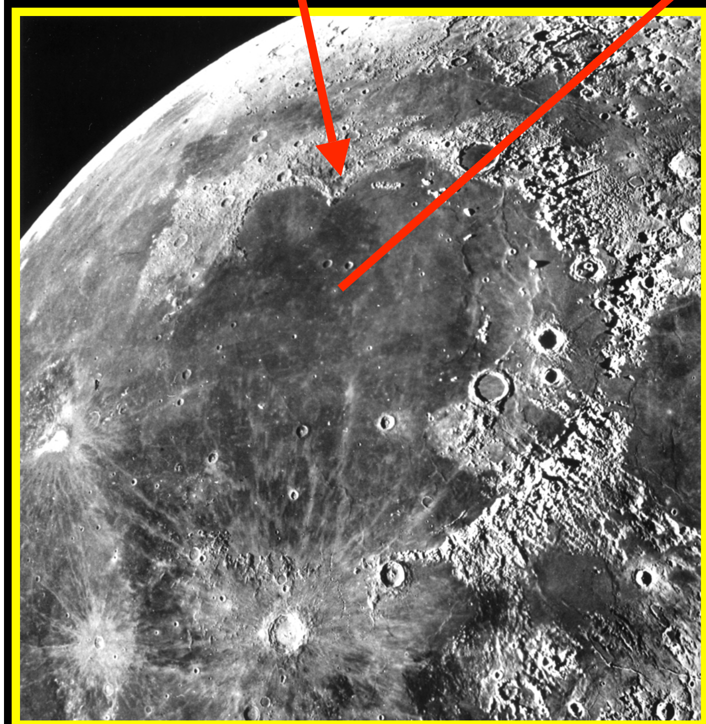
Polymict Breccia 72275

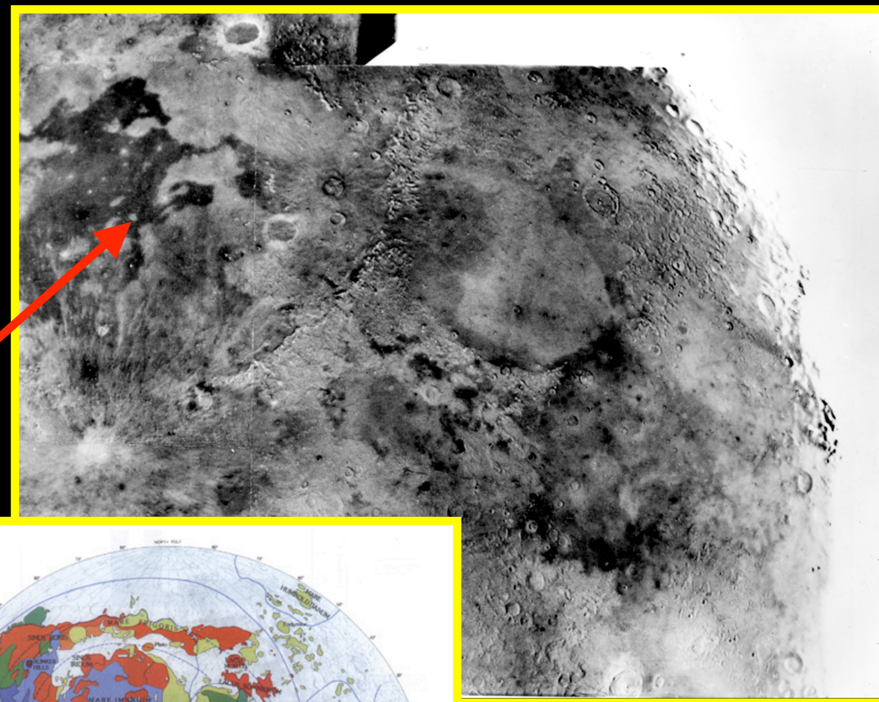


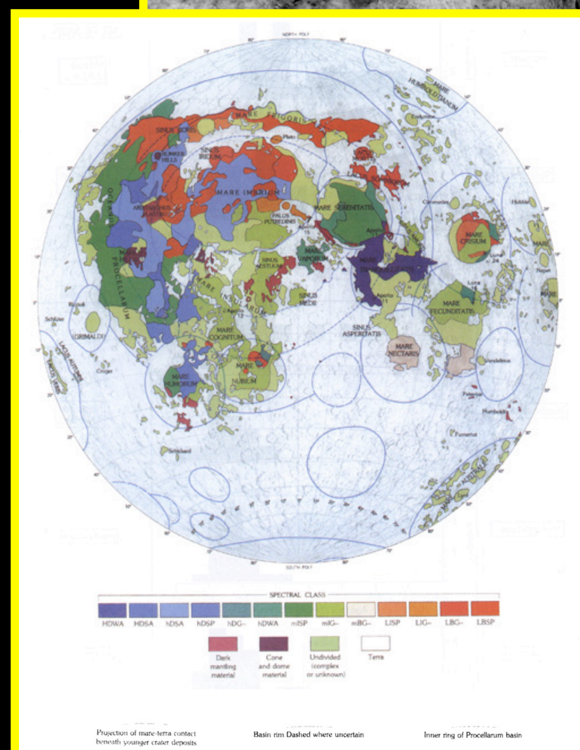
Anorthosite 60025

Distinguishing, Characterizing Mare Basalt Units





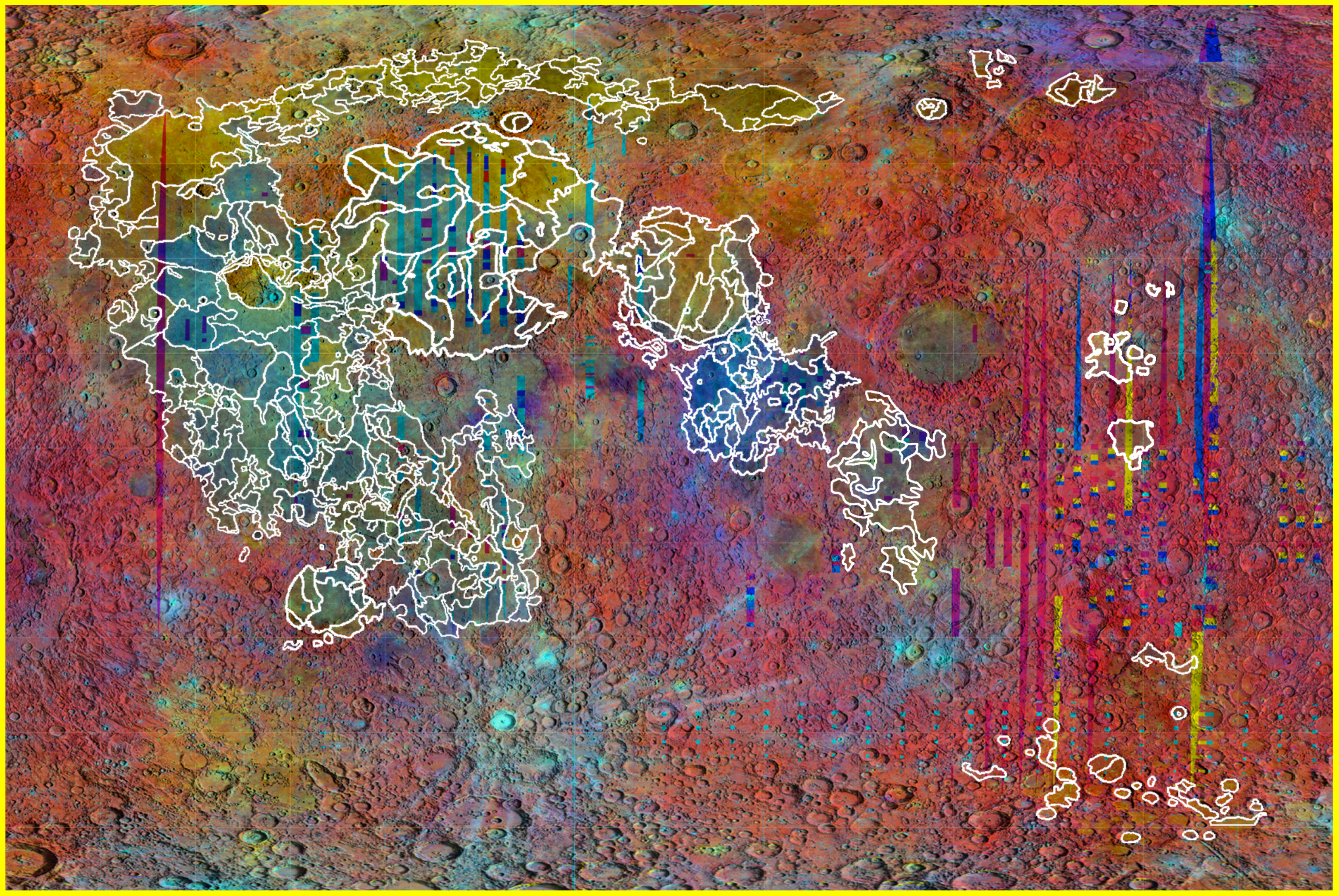




Definition: Ewen Whitaker

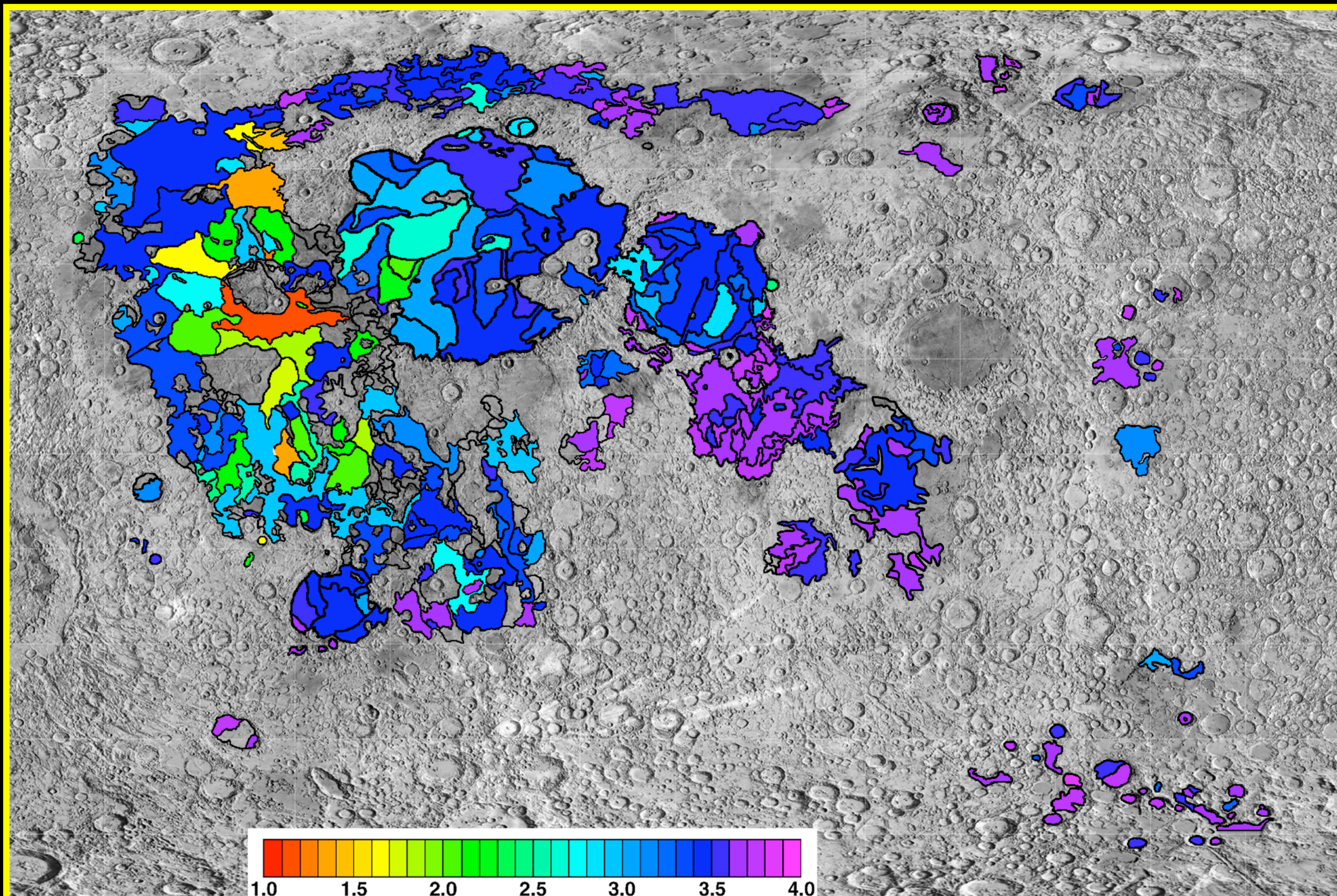
Definition and Characterization:
Carle Pieters,
Tom McCord,
John Adams,
Paul Lucey

Defining/Characterizing Mare Basalt Units



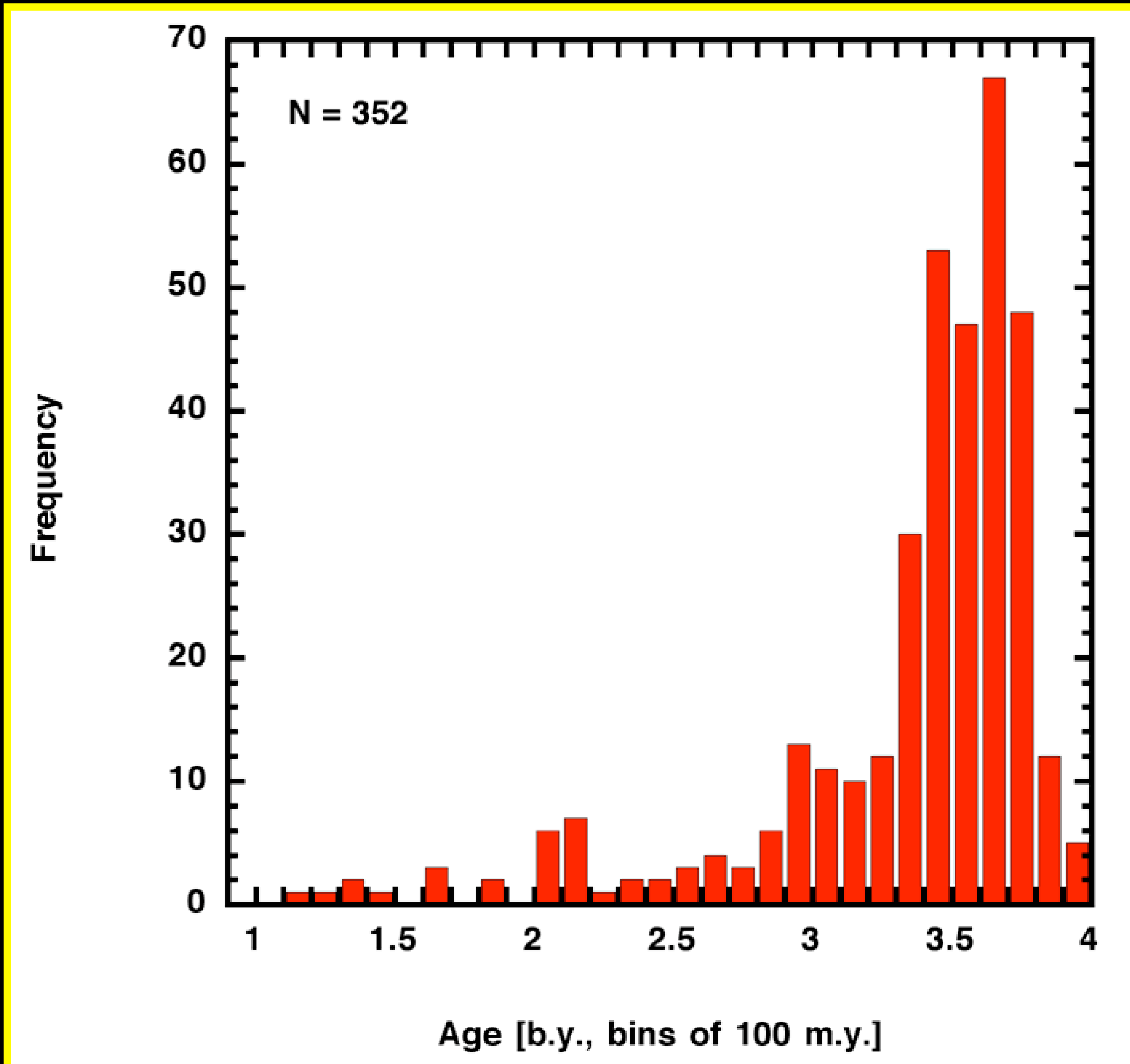
Galileo, Clementine multispectral images

Dating Distinctive Mare Basalts Units



(Hiesinger et al., 2000, 2002, 2003, 2008; Hiesinger and Head, 2006)

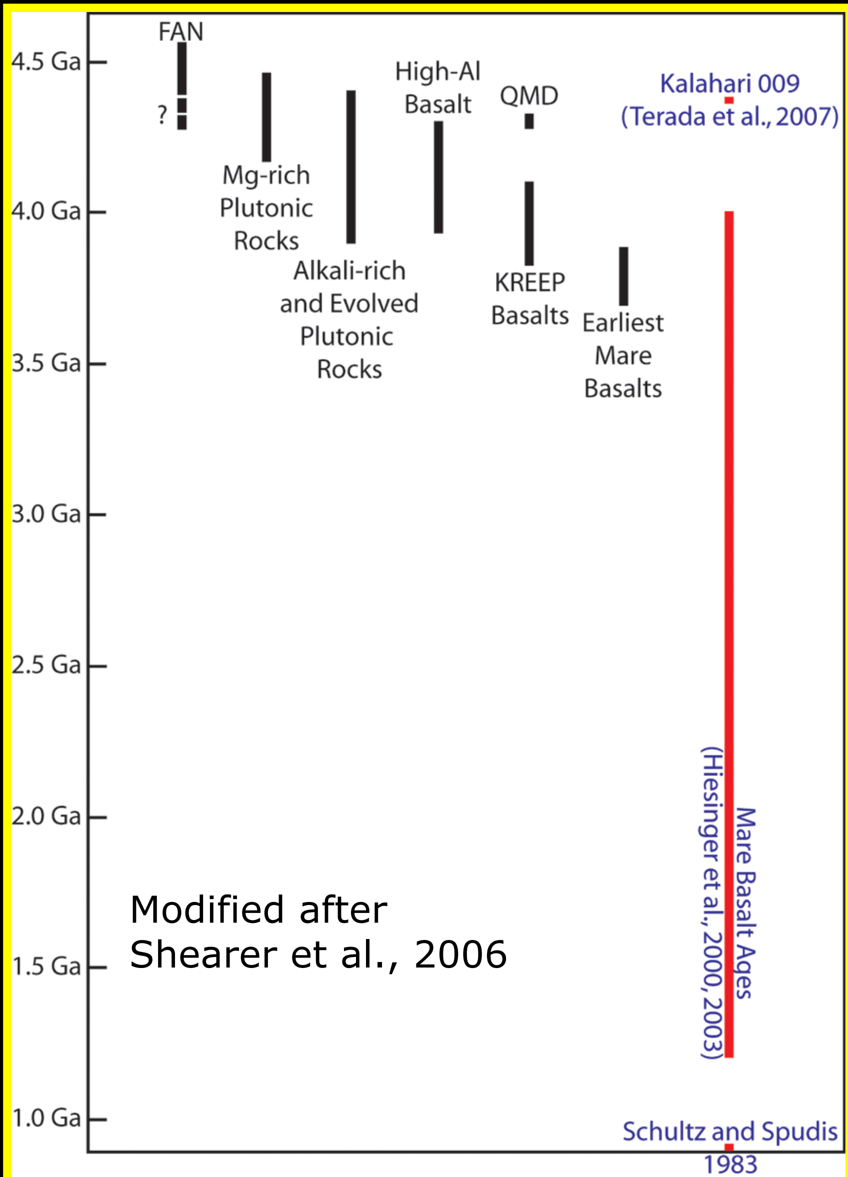
Ages of Mare Basalts: Frequency Distribution/Flux

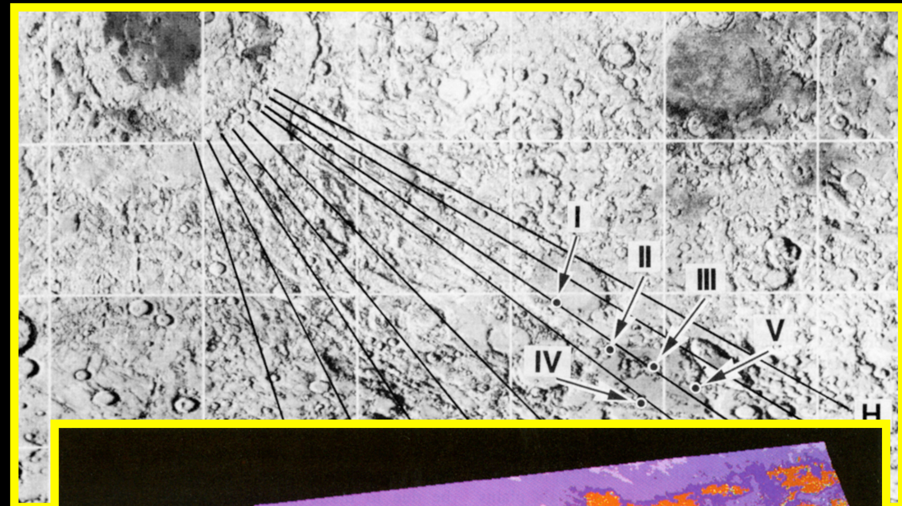


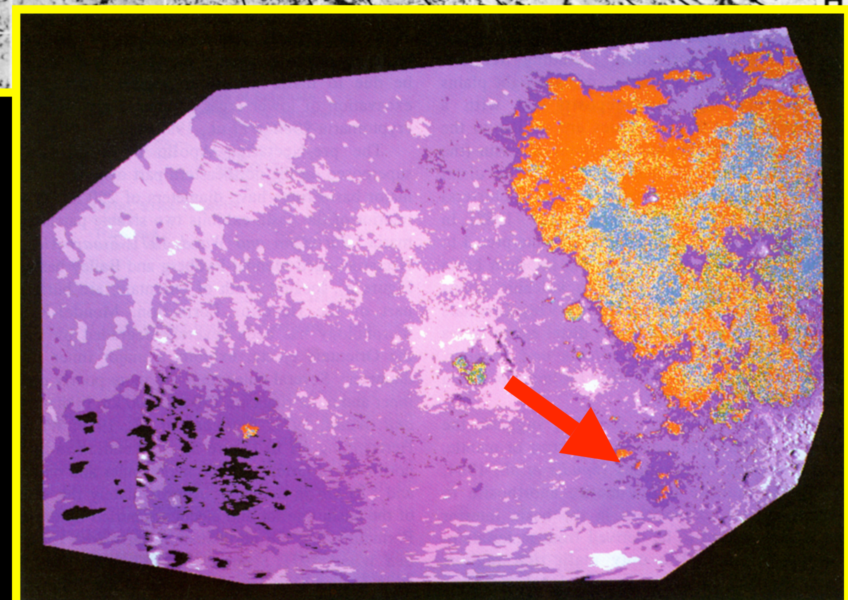
Investigated Areas:
Mare Australe
Mare Cognitum
Mare Frigoris
Mare Imbrium
Mare Humorum
Mare Humboldtianum
Mare Insularum
Mare Marginis
Mare Nectaris
Mare Nubium
Mare Serenitatis
Mare Smythii
Mare Tranquillitatis
Mare Vaporum
Oceanus Procellarum
Several lava-filled craters
Sinus Medii

Ages: When is Onset of Mare Basalt Volcanism?

Evidence from Samples

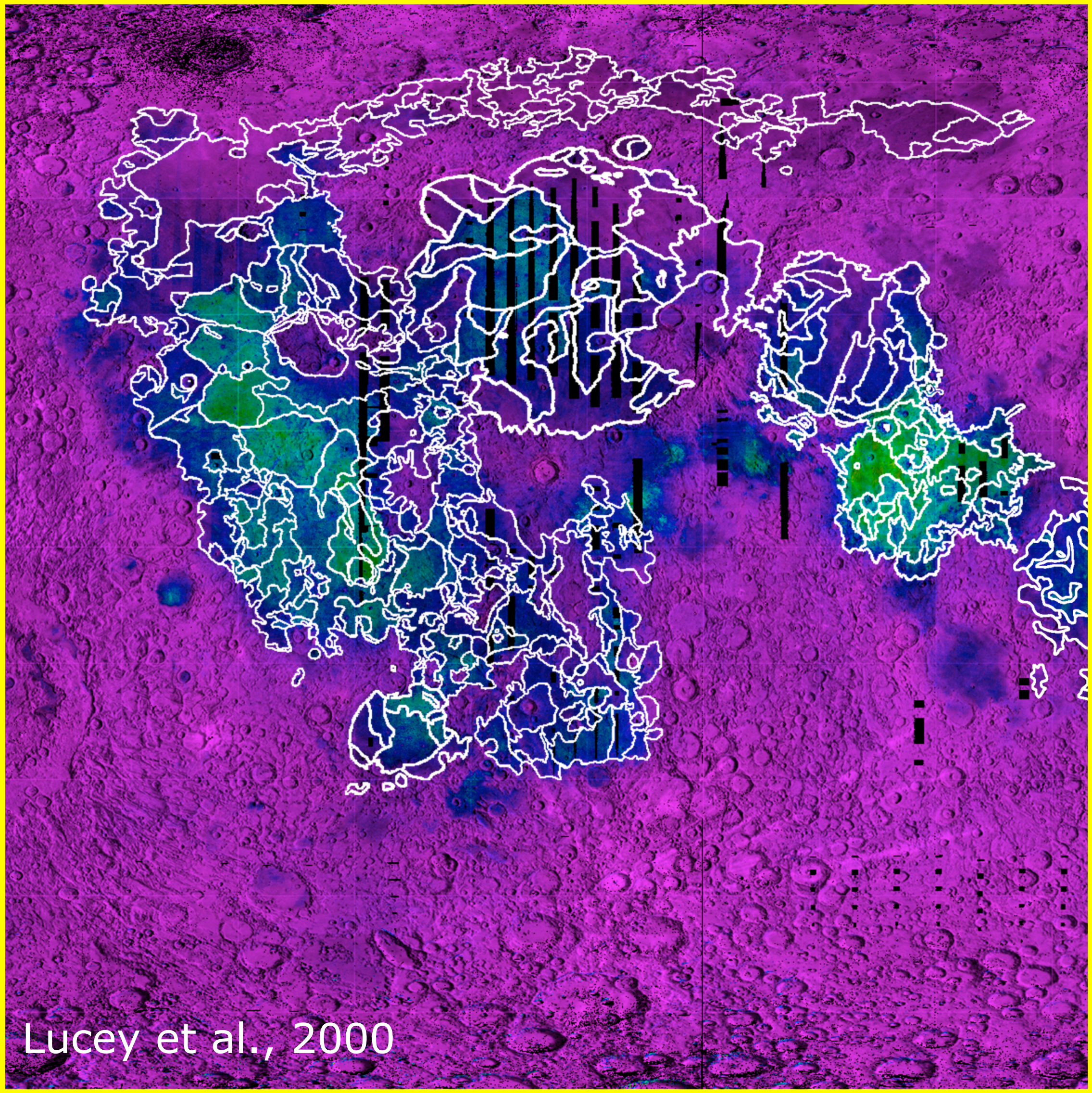


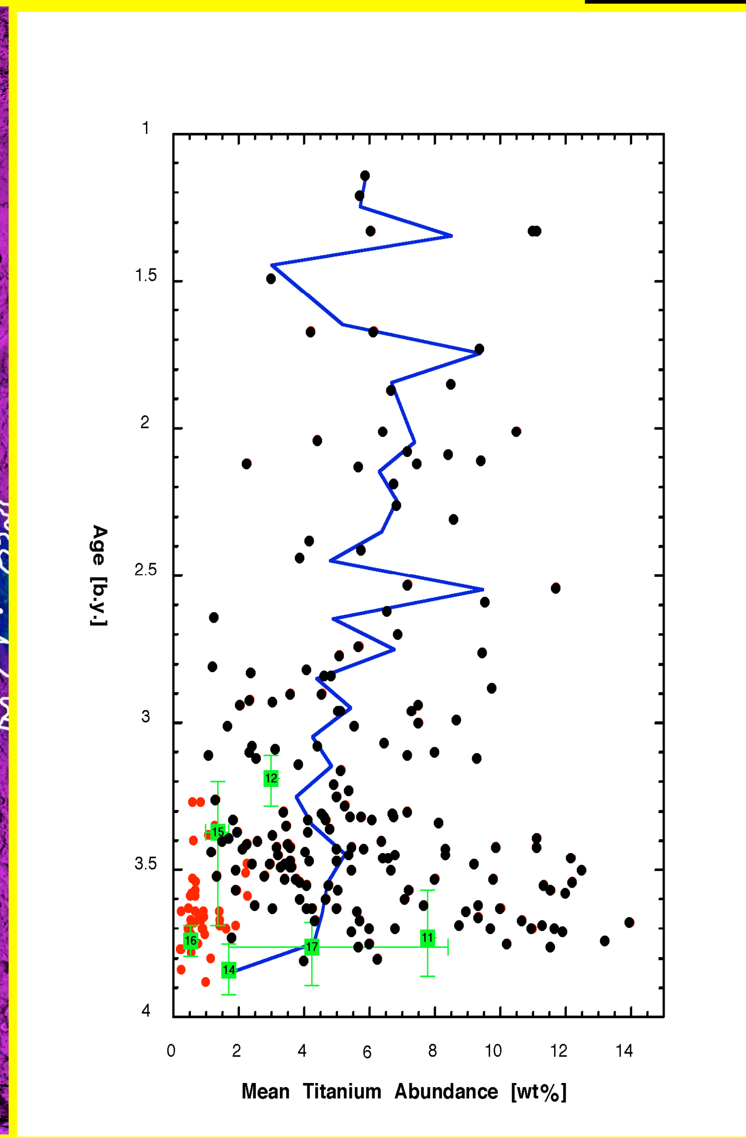




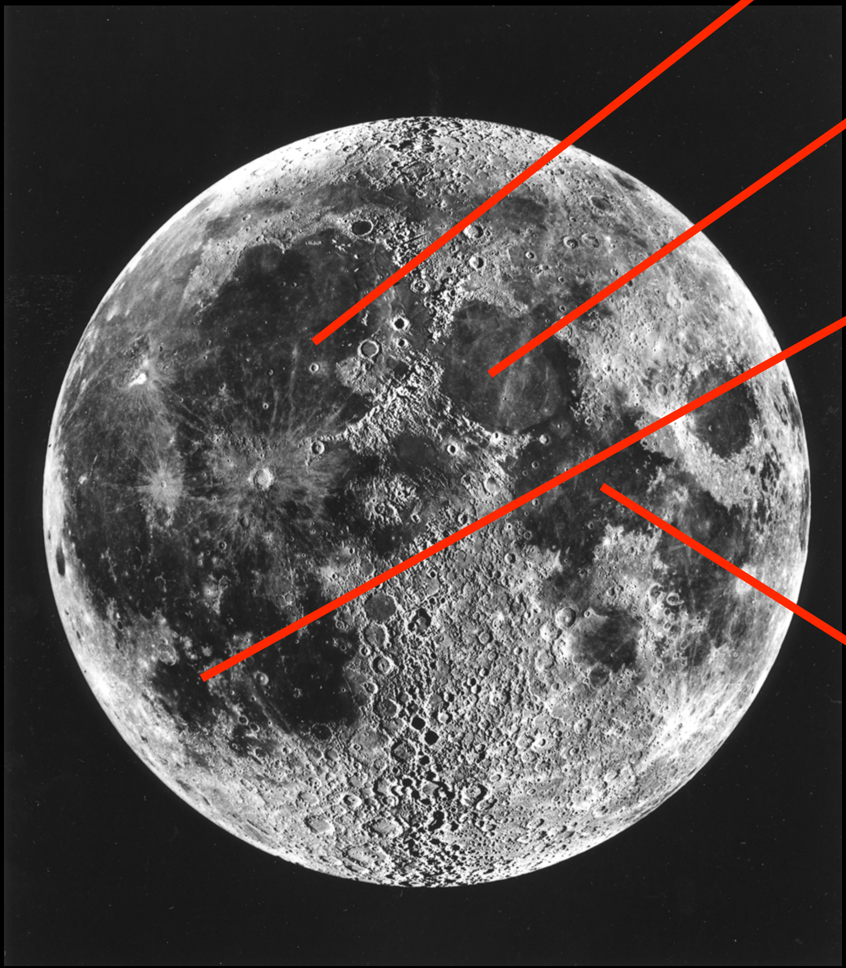
Evidence from Cryptomaria (Pre-Orientale Mare Deposits)

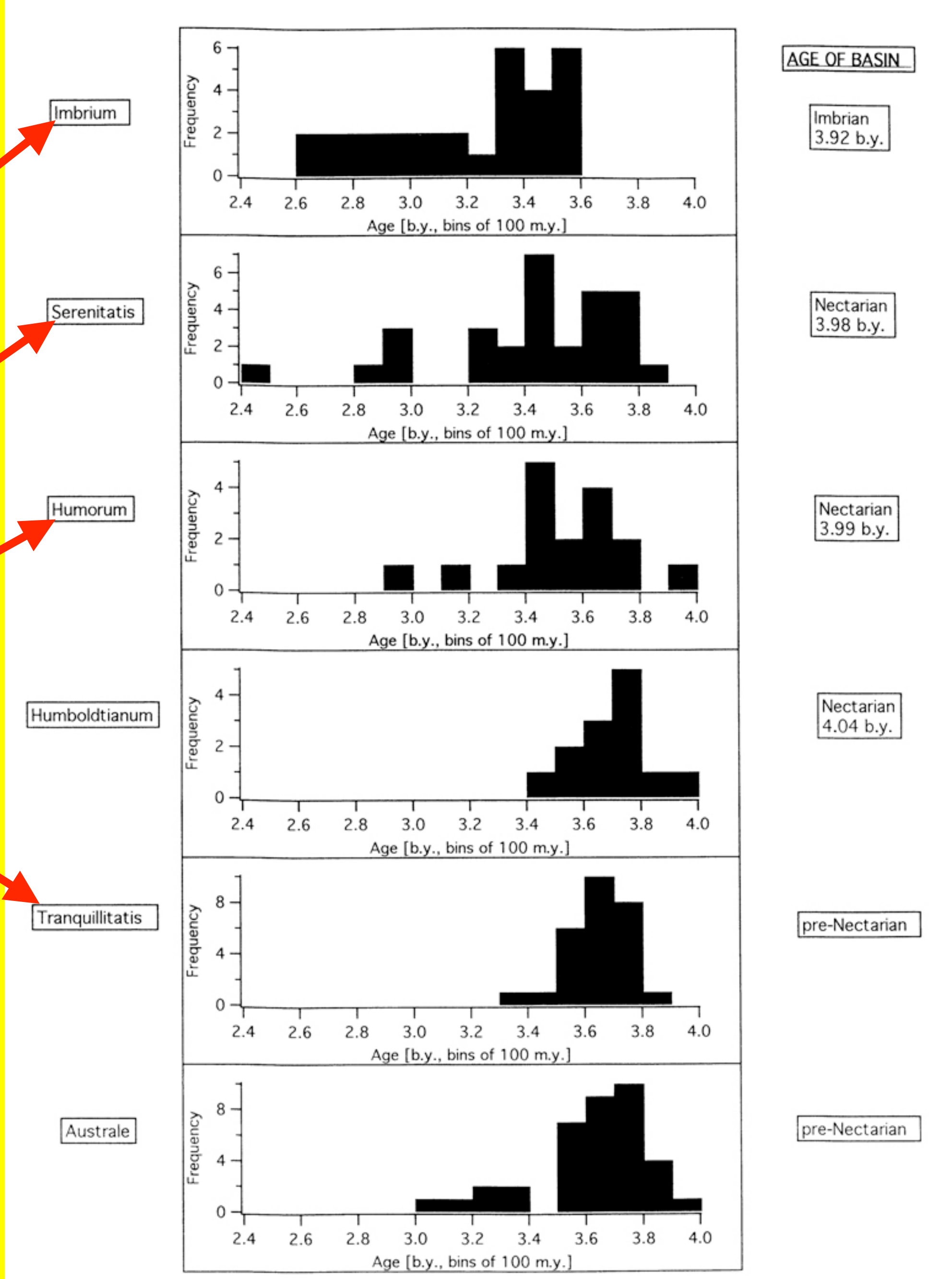
Mineralogy/Composition and Ages of Mare Basalts

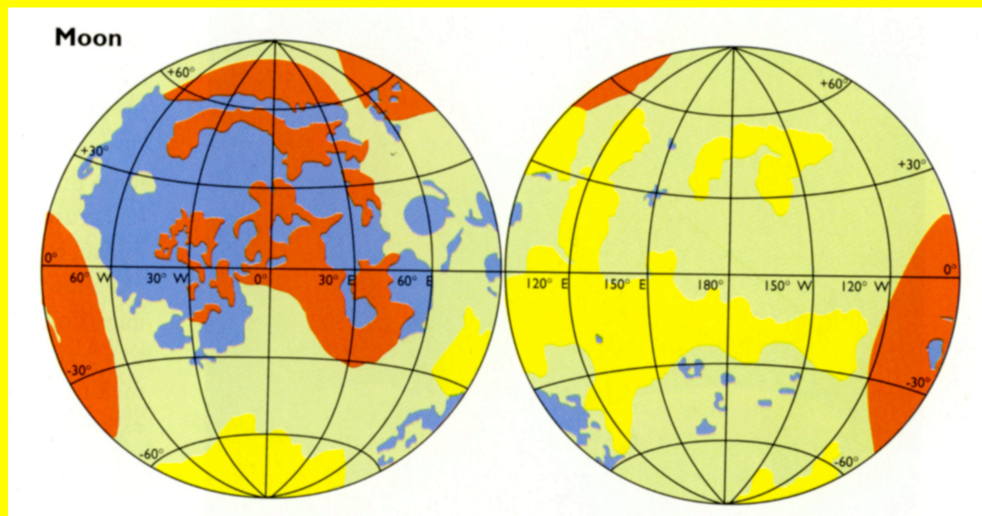


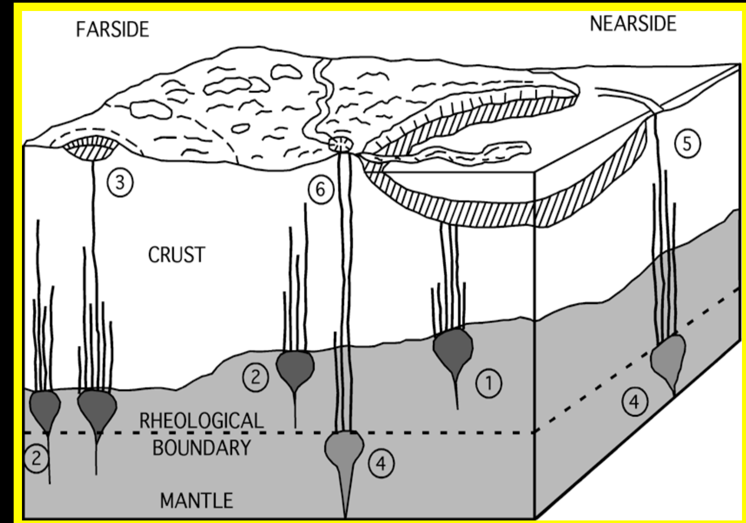


Duration of Mare Basalts In Individual Impact Basins



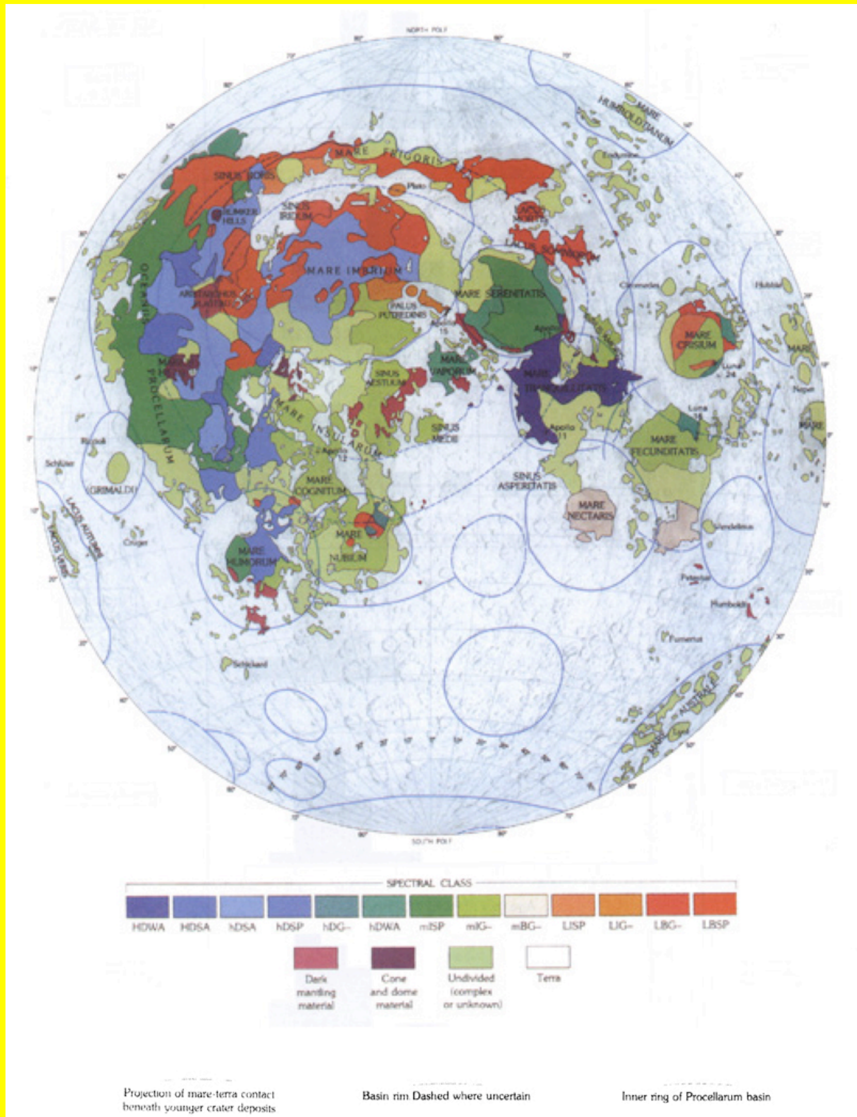






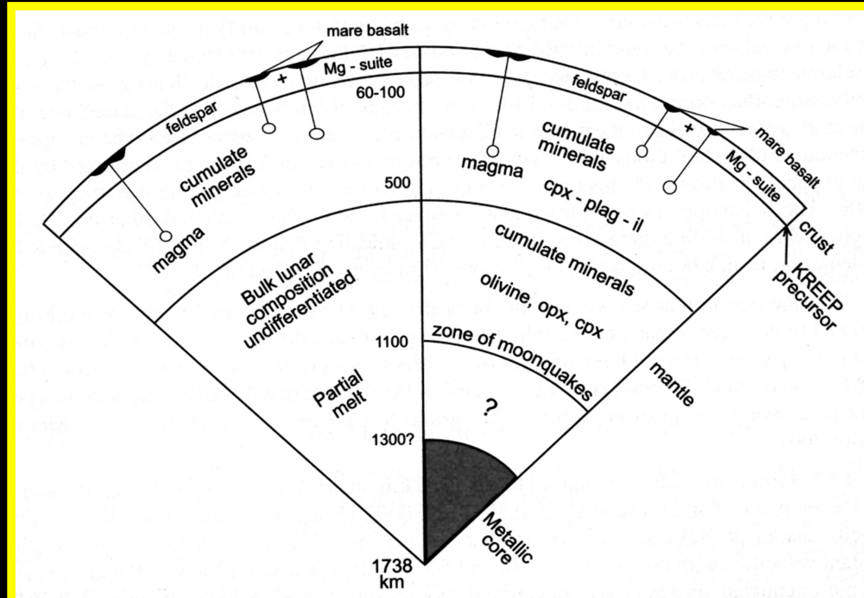
- -Basaltic volcanism petrogenesis on a one-plate planet.
- -Mare deposits: Sampling internal heat and composition.
  - -17% of surface; NS/FS asymmetry; V = 10^7 km^3; ~1% of crust.
  - -Duration is ~3 b.y., but peak flux is early, in Imbrian (3.3-3.8).
- -Very low mean flux, very high short-term flux.
  - -Mean flux 10^{-2} km^3/a, similar to Kilauea today.
  - -Single eruption may represent 30,000 years of mean flux.
- -Wide diversity of basalt lithologies and mineralogies.
- -Primary crust is a low-density crustal density barrier.
  - -Role of huge impacts in generation of mare basalts.
  - -Moon is cooling; lithosphere thickening with time.
  - -Importance of instabilities in layered interior, aftermath!

Testing Models of Lunar Mare Basalt Petrogenesis: Key to Understanding Lunar Chemical and Thermal History



(C. Pieters)

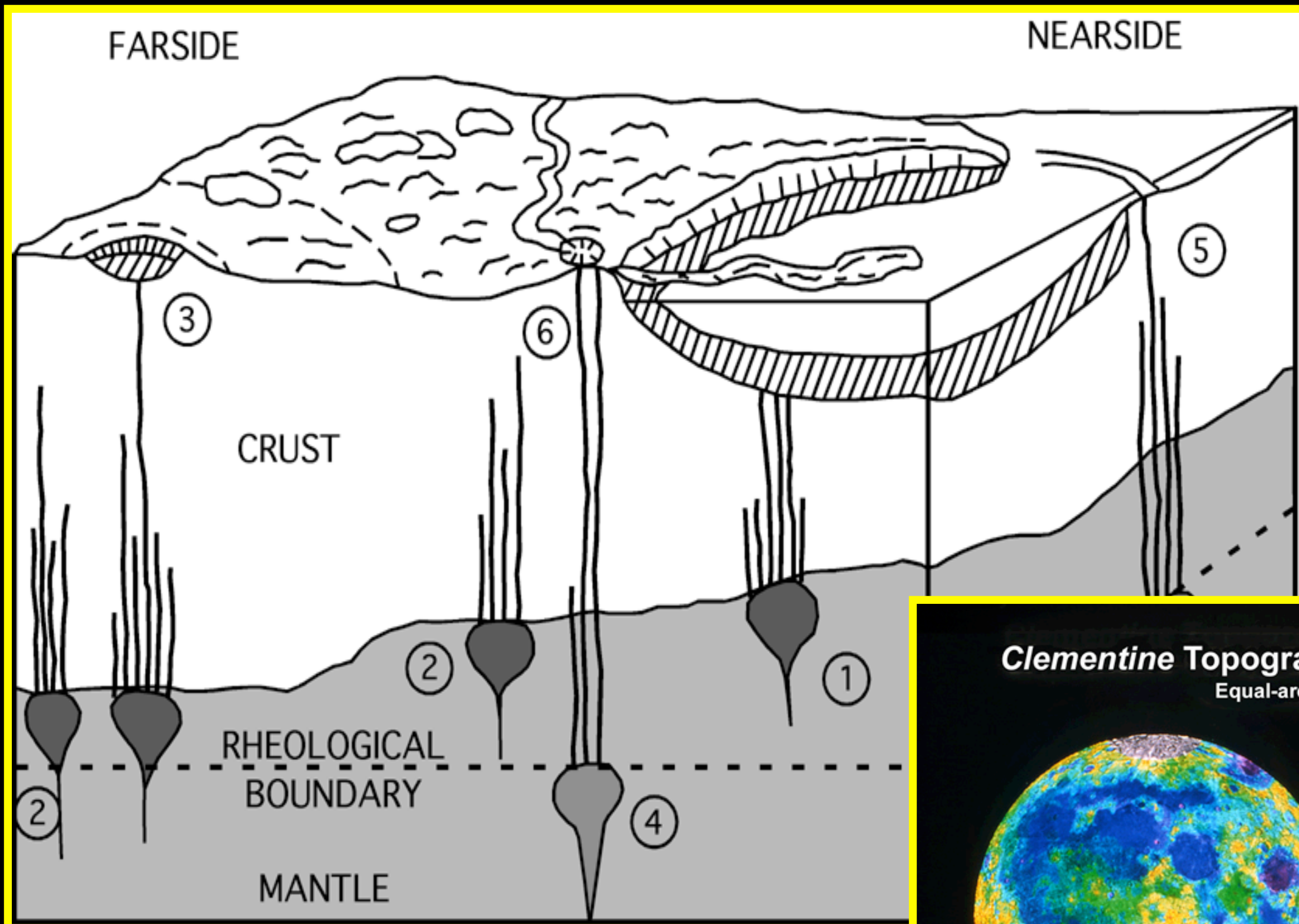
-Early models dominated by A11-12 returned samples.
-Later models more complex, still sample dominated.



(Taylor et al., 2006)

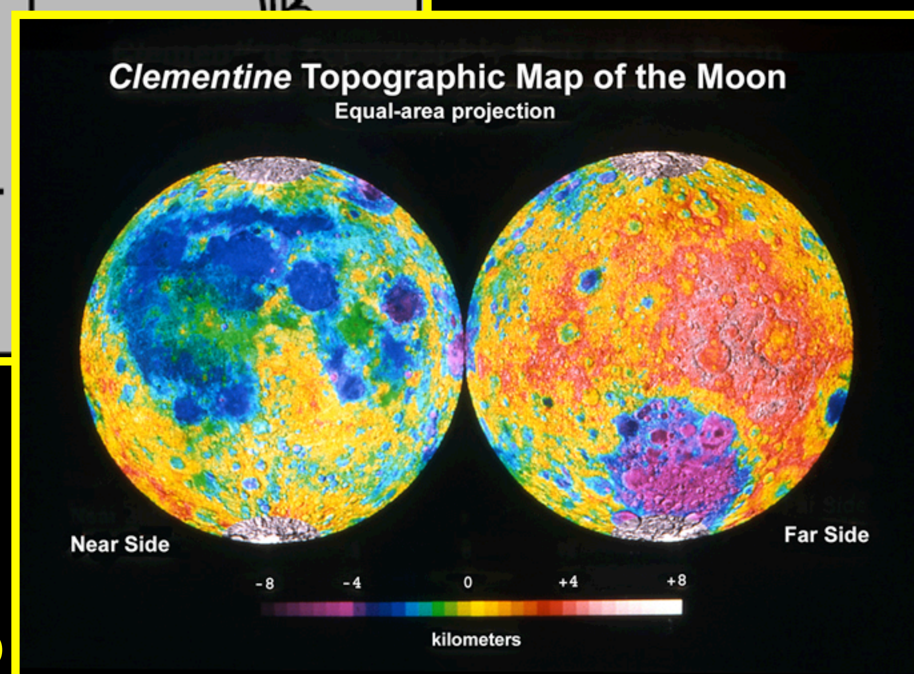
-Assess models linked to other geological processes (impact), geophysical, remote sensing data.

Crustal Thickness Differences Control NS/FS Mare Asymmetry



(Head and Wilson, 1992)

1. Buoyant diapirs rise to density trap.
2. Overpressurize, propagate dikes into crust, toward surface.
3. Thinner crust on nearside permits easy access to surface

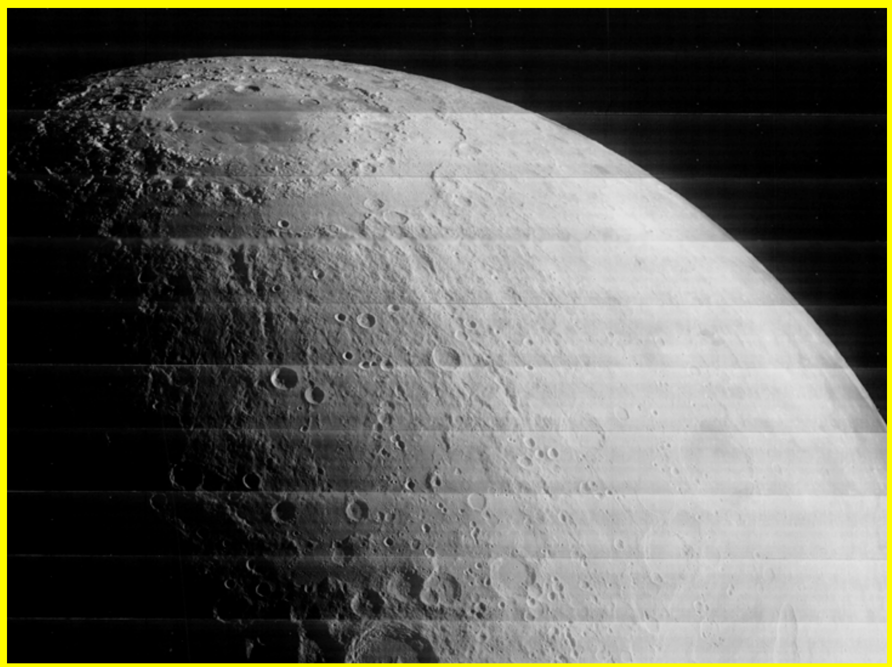


1. Clementine altimetry data revealed depth of farside SPA basin: Very deep.
2. Thin crust on basin floor.
3. Little maria on floor of basin. .

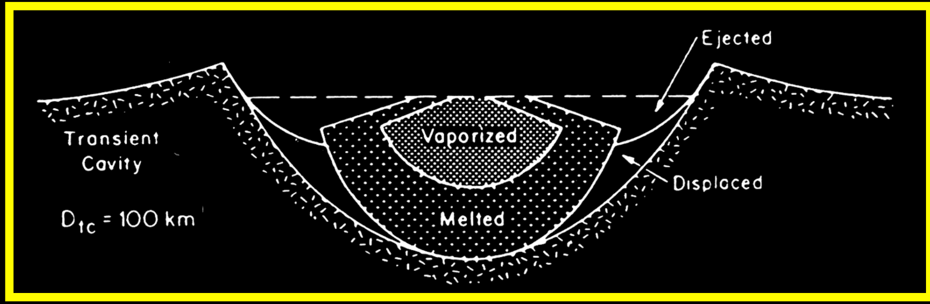
(Zuber et al., 1994)

Impact Basin Pressure-Release Melting and Associated Secondary Convection

(Elkins-Tanton et al., 2004; Ghods and Arkani-Hamed, 2007)

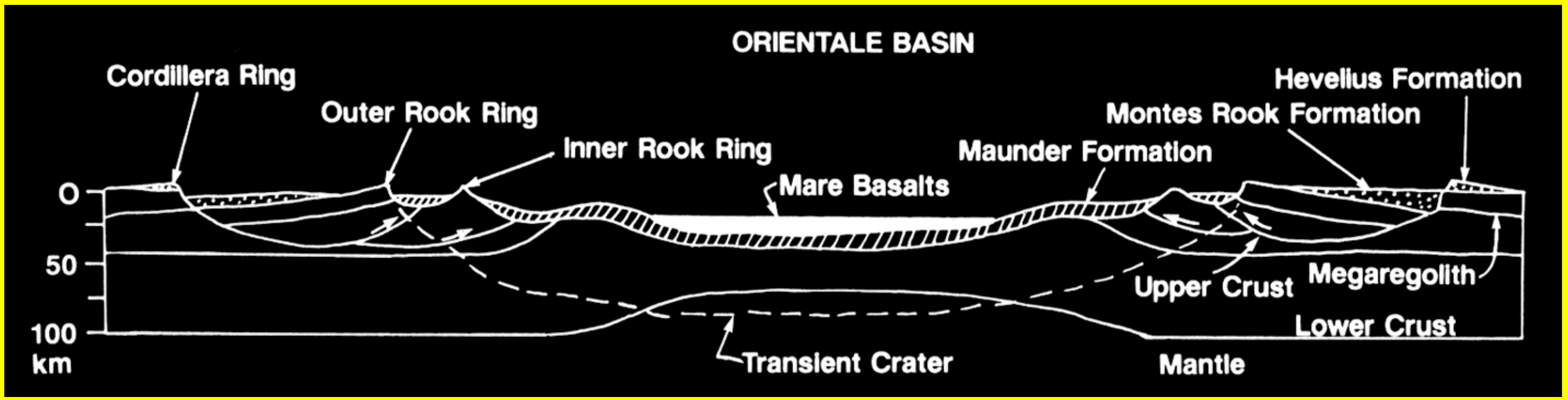


Impact basin formation.



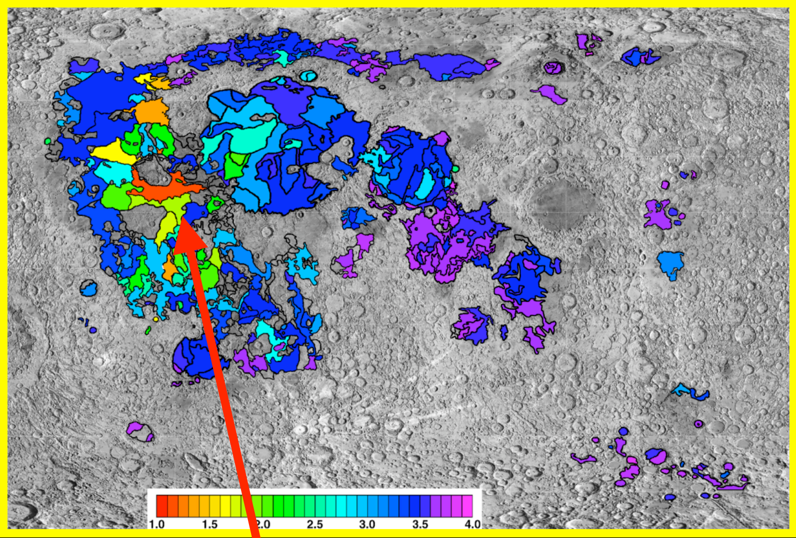
1. Mantle in situ pressure-release melting: Instantaneous; near basin formation.
2. Uplift-induced secondary convection, adiabatic melting: Lasts up to 350 m.y.

Basin collapse, isotherm uplift.

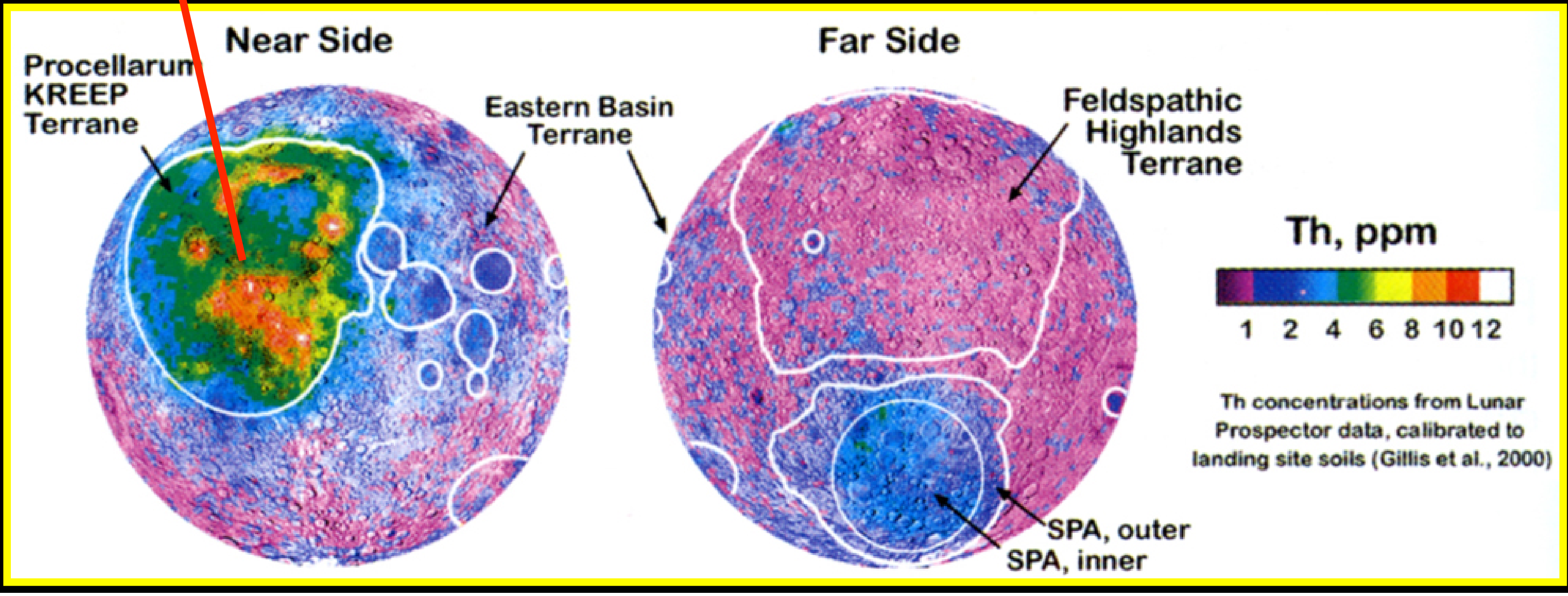


Enhanced KREEP Layer in Procellarum KREEP Terrain (PKT) Explains Generation, Distribution, Emplacement

(Wieczorek and Phillips, 2000)

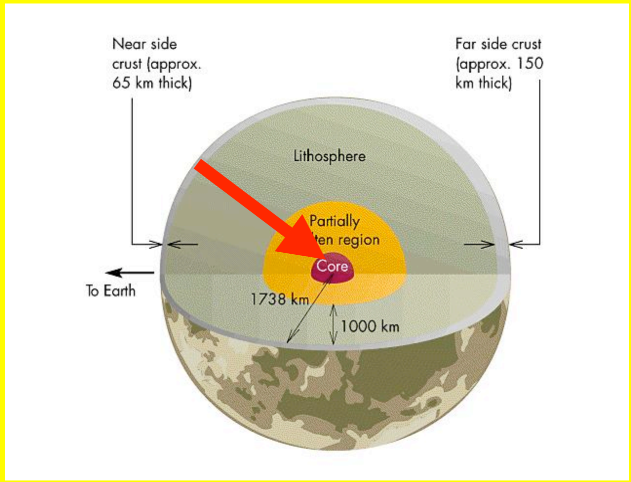


1. PKT makes up ~16% of lunar surface.
2. But, >60% of mare basalts occur there.
3. Cause and effect: KREEP->mare basalts.
4. KREEP layer heat partially melts mantle.
5. Begins immediately, continues to present.
6. Source becomes deeper with time.



Initially Unstable Stratification: Large-Scale Overturn and Aftermath

(Hess and Parmentier, 1995)



Anorthositic Crust

Magma Ocean Cumulates

(dense ilmenite-rich cumulates with high concentration of incompatible radioactive elements)

(olivine-orthopyroxene cumulates; later-crystallized, denser, more Fe-rich compositions at top)

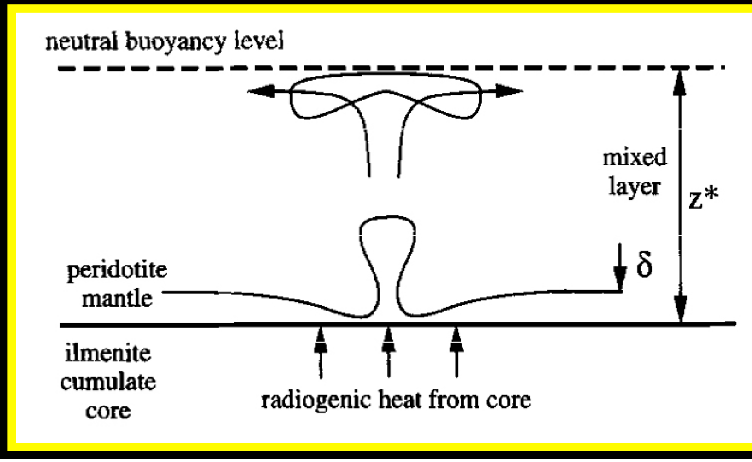
Primitive Lunar interior

-The Prelude-

1. Lunar Magma Ocean (LMO) crystallization.
2. Forms chemically stratified interior.
3. Cumulate layers are gravitationally unstable.
4. Rayleigh-Taylor instabilities cause dense cumulates to sink toward center of Moon.

-The Aftermath-

5. Dense cumulates form core.
6. Ilmenite-rich cumulate core undergoes radioactive heating, melts overlying mantle.
7. Thermal plumes rise into chemically stratified surroundings; mixing, homogenization.
8. Melting at top of mixed layer produces mare basalts.
9. Onset time is post-overturn, duration is long.



Ongoing Key Tests for Mare Basalt Petrogenesis Models

-Duration of mare basalt emplacement:

- -Lunar-wide.
- -Within individual impact basins.

-Mineralogy of mare basalts:

- -Time and space distribution.

-Relation to crustal terrains (e.g., PKT).

-Volumes of basalt eruptions and depths.

-Styles of mare basalt activity:

- -Deep interior, upper mantle, crustal.

-Lunar farside mare basalt record.

-International armada: Provides critical data!